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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 499

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER February 12, 1917

THE MULCHED-BASIN SYSTEM OF IRRIGATED CITRUS CULTURE AND ITS BEARING ON THE CONTROL OF MOTTLE-LEAF

By

LYMAN J. BRIGGS, Biophysicist in Charge, C. A. JENSEN, Assistant in Plant Malnutrition Investigations, and J. W. McLANE, Laboratory Assistant, Office of Biophysical Investigations

CONTENTS

	Page
Introduction	1
Cultural Practice in the Citrus Districts of California	3
Plowsole	4
Organic Mulching	4
The Mulched Basin	6
Moisture Determinations in the Sunny Mountain Grove	7
Soil-Moisture Measurements in Basins, under Cover Crops and under a Soil Mulch in the Vivienda Grove	8
Basin and Cover-Crop Experiments in the Victoria Grove	11
Furrow Irrigation Often not Adequate	13
Lateral Movement of Soil Moisture Very Slight	13
Summer Cover Crops in Orange Groves not Practicable without an Increased Water Supply	14
Organic Mulches More Effective than Soil Mulches in Conserving Water	14
Effect of Basining on Tree Growth	15
The Mulched Basin in Relation to Soil Type	16
Effect of the Mulched Basins on Soil Conditions and Root Growth	17
Fruit Setting and Tree Growth as Influenced by the Mulching Material	18
Size of Basins	23
Cost of Preparing and Maintaining the Basins and the Mulch	24
Limitations of the Mulched-Basin System	25
Humus Content of the Basins and the Check Soils	26
Summary	28

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CONTENTS.

	Page.
Introduction	1
Cultural practice in the citrus districts of California	3
Plowsole	4
Organic mulching	4
The mulched basin	6
Moisture determinations in the Sunny Mountain grove	7
Soil-moisture measurements in basins, under cover crops and under a soil mulch in the Vivienda grove	8
Basin and cover-crop experiments in the Victoria grove	11
Furrow irrigation often not adequate	13
Lateral movement of soil moisture very slight	13
Summer cover crops in orange groves not practicable without an increased water supply	14
Organic mulches more effective than soil mulches in conserving water	14
Effect of basining on tree growth	15
The mulched basin in relation to soil type	16
Effect of the mulched basins on soil conditions and root growth	17
Fruit setting and tree growth as influenced by the mulching material	18
Size of basins	23
Cost of preparing and maintaining the basins and the mulch	24
Limitations of the mulched-basin system	25
Humus content of the basins and the check soils	26
Summary	28

INTRODUCTION.

Orange and lemon trees in California are subject to a functional disturbance known as mottle-leaf, which in its advanced stages results in a marked reduction in the yield and quality of the fruit. The characteristics of mottle-leaf have been discussed in a recent

[1] The writers take this opportunity to express their obligation to the University of California Citrus Experiment Station and Graduate School of Tropical Agriculture at Riverside for the courtesies and facilities extended during the course of this work, and to the growers who have placed groves at the disposal of the Government for experimental purposes and who have provided the labor and materials necessary for the prosecution of the field experiments.

paper[1] dealing with a field and laboratory study of the relation of mottle-leaf to soil conditions. In that paper it was shown by statistical methods that the percentage of mottling in 120 orange groves studied was inversely correlated to the extent of 0.67 with the humus content of the soil, as represented by the organic matter extracted with 4 per cent ammonium hydroxid and determined colorimetrically by comparison with a freshly prepared gravimetric standard. In other words, one-half of the mottling is associated with and is apparently due to a deficiency in the humus content. The investigations of Schreiner and his colleagues, Shorey, Lathrop, and Walters, have demonstrated that the organic matter extracted from soil by an alkaline solution is a varying mixture of numerous organic compounds having widely different properties.[2] If the humus components which are active and perhaps essential in maintaining the nutrition of the orange trees could have been separated from the mixture, a still higher inverse correlation would probably have been obtained between the amount of these essential or active constituents and the percentage of mottling. The analytical difficulties involved, however, combined with the incompleteness of our knowledge regarding the active constituents of the humus, made such a procedure impracticable.

Mottle-leaf, however, is apparently not associated wholly with the low humus content of the soil. Groves which have been fertilized chiefly with manure and green cover crops are by no means always free from mottle-leaf. The evidence collected in the above-mentioned field survey indicated that the furrow system of irrigation and the intensive surface cultivation in vogue in these districts may be in part responsible for the deterioration of the groves. The present bulletin deals with an investigation of this phase of the problem. Special attention is given to a new method of citrus culture, which the writers have termed the mulched-basin system, in which the trees are irrigated by means of basins heavily mulched with organic material, the soluble organic compounds resulting from the decomposition of the mulch being carried by the irrigation water into the soil. The soil-moisture conditions and the yields under the mulched-basin system and the furrow-irrigation system are compared, and the results of determinations of the rate of increase of the humus content of the soil under the mulched-basin system are presented.

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[1] Briggs, L. J., Jensen, C. A., and McLane, J. W. Mottle-leaf of citrus trees in relation to soil conditions. *In* Jour. Agr. Research, v. 6, no. 19, p. 721–739, pl. H and 96–97. 1916.

[2] Schreiner, O., and Shorey, E. C. Chemical nature of soil organic matter. U. S. Dept. Agr., Bur. Soils Bul. 74, 48 p., 1 pl. 1910.

Lathrop, E. C. Protein decomposition in soils. *In* Soil Science, v. 1, no. 6, p. 509–532. 1916.

CULTURAL PRACTICE IN THE CITRUS DISTRICTS OF CALIFORNIA.

Irrigation is necessary in all the citrus districts of California, the rainfall being confined almost wholly to the winter months. The location of many of the groves on high land near the foothills, in order to lessen the danger of frost injury, has necessitated pumping water to high levels, with a proportionate increase in the cost. The limited water supply and its high cost have in turn led to the nearly universal practice of maintaining a deep soil mulch throughout the grove during the summer months, in order to conserve the moisture supply as much as possible.

The groves are usually irrigated through furrows about every 30 days during the summer. Three to five furrows are made between the tree rows, extending through the mulch to the uncultivated soil. As soon as the soil is dry enough after irrigation to permit working, the furrows are closed and the mulch again established. In the Riverside district the furrows are not, as a rule, led under the trees or between the trees in the tree row, so that the soil in the tree row (nearly half the total area) receives no irrigation water directly. The lateral movement of water in many of the soils studied is so slight that the soil in the tree row receives very little water during the summer and often becomes very dry and hard.

The feeding root system of citrus trees is usually shallow, and deep plowing results in a severe root pruning. It is perhaps on this account that deep plowing is not more often practiced. Cover crops are sometimes grown during the winter, and these are plowed under if heavy; but the disk harrow is more commonly used to work manure and fertilizer into the soil.

ACCUMULATION OF PLANT FOOD IN THE SURFACE SOIL UNDER FURROW IRRIGATION.

The bottom of the irrigation furrow is usually below the cultivated soil. The water is consequently applied for the most part below the soil containing the fertilizer. During irrigation the water moves upward by capillary action from the bottom of the furrow into the surface soil containing the fertilizer, but there is little or no downward movement of the water through the fertilized layer of soil into the root zone. After irrigation the upward capillary movement of the soil solution continues for a time, the soluble salts being carried to the surface, where they are deposited as the moisture evaporates. The result is that the plant-food elements reach the root zone very slowly, the tendency being for the soluble constituents to accumulate in the cultivated surface soil, where there is practically no root development. It is only during the rainy season that there is any appreciable downward movement of the water through this surface soil into the root zone.

The accumulation of the soluble soil constituents near the surface is strikingly in evidence during the summer months in almost any heavily fertilized grove under furrow irrigation. The sides of the furrows and the surface of the ridges between the furrows will be found coated with a brown crust which closely resembles an ordinary "alkali" crust as seen in saline districts. This crust has been found by Breazeale to be so rich in soluble salts that it will kill young seedling oranges or lemons, the seedlings sometimes dying overnight. The soils of the area do not normally contain enough soluble matter to bear any resemblance to "alkali" soils; but these surface crusts illustrate very strikingly the tendency under this system of fertilization and irrigation of the soluble constituents to move into and accumulate in the surface soil.

PLOWSOLE.

Furrow irrigation and intensive surface cultivation often promote the formation of a "plowsole," or incipient hardpan, under the soil mulch, varying in thickness from 3 inches to 2 feet. This layer of soil beneath the mulch frequently becomes so hard as to polish under the point of the plow when the irrigation furrows are opened. A long time is required for irrigation water to penetrate it, and it offers a serious obstacle to the development of the roots of citrus trees. Deep plowing loosens the plowsole temporarily, but destroys the roots to the depth of plowing, and the plowsole soon forms again.

ORGANIC MULCHING.

The study of the cause of mottle-leaf led to experiments having as their object the development of a method of fertilizing and irrigating citrus trees which would avoid the objections of the present system. The use of surface mulches of organic material, such as straw, manure, damaged alfalfa, etc., as a substitute for the intensive cultivation was suggested in 1912 by one of the writers as a possible solution of the problem.[1] A trial of the organic surface mulch was inaugurated in 1913 on a small field plat of lemons on the Limoneria Ranch near Santa Paula, Cal. Under date of February 24, 1915, Mr. James Culbertson, assistant manager of the Limoneira Co., reported upon this experiment as follows:

> You will doubtless remember our discussion . . . a year ago last December when the possible value of mulching as a corrective for chlorosis was the topic. Upon reaching home I had three short rows thoroughly mulched, one with sawdust, one with bean straw, and the third with fairly well rotted manure. They were not in the worst affected areas. Later in the spring, in May, when

[1] At a meeting of the California Lemon Club, at which this idea was advanced, Prof. H. S. Fawcett, of the University of California Citrus Experiment Station, reported an orange grove on an island near the eastern coast of Florida that for many years had been successfully operated under the mulching system without cultivation; and he has since observed the organic mulch in use in Cuba.

Prof. Fawcett had returned from a trip to Florida and Cuba and brought back reports of having seen very marked recovery of trees, apparently similarly affected, brought about by heavy mulch, we selected six rows 49 trees long through the very center of our worst affected area. We first plowed the ground and, after running three large furrows for irrigation, covered three of these rows, spaces and all, with manure and three of them with bean straw to a depth of 4 to 6 inches. From the road in the valley below looking up toward the hill slope where this orchard lies one can see these six rows standing out in contrast like a belt of green ribbon across a yellow background. It is remarkable, and all in nine months. Later observations from the near-by hills reveal the fact that the small tract mulched over two years ago is also darker green than the surrounding orchard, though the contrast is not so great, because it lay among healthy trees and was itself a group of normal trees.[1]

While surface mulching of orchard trees in humid regions with organic material has long been practiced on a small scale, it has not, in the United States at least, been followed to any great extent. The results of recently reported investigations in Pennsylvania by Stewart [2] indicate, however, that surface mulches of strawy manure, alfalfa hay, or other organic material may be used with advantage and profit in the culture of apples on a commercial scale. Stewart summarizes his investigations in part as follows:

In general the mulch treatment, reinforced by outside materials, has been most efficient in improving the yield, growth, and average size of fruit in orchards up to about 20 years of age. In older orchards it has been surpassed slightly by tillage and cover crops, unless accompanied by adequate fertilization. It has also been most efficient in conserving moisture in all cases that have been determined.

The crop value of the present mulch has averaged 76½ bushels per acre annually in the seven normal comparisons available. Its annual gain over tillage and cover crops has averaged 15.8 bushels per acre in the same experiments. The mulch is therefore a valuable treatment when properly managed and when mulching materials are available at not over $7 per ton, unless tillage is not practicable. All mulches should be kept at least a foot away from the tree trunks, and a greater distance is desirable as the trees enlarge.

Fawcett,[3] of the California Citrus Experiment Station, has recently made the following observations regarding the use of organic mulches in citrus groves in Cuba, where the distribution of the rainfall is similar to that in Florida, the greater part occurring during the summer months:

At Herradura, Prof. F. S. Earle showed the writer a grapefruit grove on clay-loam soil underlain with stiff clay, where part of the grove had been mulched

[1] As this bulletin is going to press Mr. Culbertson informs the writers that the six rows of mulched trees yielded 36 per cent more fruit in 1916 than the adjacent six rows of unmulched trees, although at the beginning of the experiment the rows selected for mulching were the lowest yielding rows in the block. At the present time (winter of 1916–17), however, the mulched rows are again becoming yellow, so that the future success of the surface mulch is still uncertain.

[2] Stewart, J. P. Cultural methods in bearing orchards. Penn. Agr. Exp. Sta. Bul. 141, 28 p., 4 fig. 1916.

[3] Fawcett, H. S. A comparison of some citrus conditions in Florida, Cuba, and California. *In* Mo. Bul. Cal. State Com. Hort., v. 5, No. 9, p. 321–337, fig. 108–117. 1916.

all over the ground. The soil in this orchard was uniform, and the trees were all of the same age—seven years. Part of the rows had been heavily mulched all over the ground with vegetable matter, grass, and weeds for three years, part of it for two years, part for 1½ years, and another part for nine months only. A few rows in the middle of the orchard had not been mulched at all, but had been plowed and cultivated to conserve moisture during the dry season, during the whole period of seven years. The difference between the mulched and unmulched trees was very marked and almost beyond belief. The trees mulched for three years past without cultivation had foliage of good color, were vigorous, comparatively free from scale insects, bearing a large amount of smooth-skinned, bright fruit, and the trees were two to four times as large in diameter of trunk and two to four times as large in spread of branches. The trees were also free from chlorosis. On the unmulched tract the trees were small, stunted, with small yellow, starved-looking leaves, with limbs dying back, and with only a very few fruits, these being russeted and inferior in quality. There was at least four to six times as much fruit on the mulched as on the unmulched trees. The trees mulched for two years instead of three also showed a proportional improvement. Even the trees mulched for only nine months showed marked improvement in color and the amount of the last new growth. The improvement in this orchard was in definite proportion to the length of time the soil had been covered with vegetable mulch.

At Santiago de las Vegas on heavy, red, sticky soil, Mr. H. A. Van Herman had been mulching heavily all over the soil for the last five years and had stopped cultivating entirely during that time. Previous to that he had practiced deep and frequent cultivation, and the trees were said to have gone back rather than forward. Since beginning this heavy mulching, the trees have grown rapidly, are healthy and green in appearance, and have on them a large crop of fruit. Mr. Van Herman was one of the first to advocate heavy mulching all over the ground as a general practice in Cuba. He is convinced that it is the proper practice for most soils in a climatic condition like that of Cuba.

Some excellent groves were seen, however, on red clay soils, and also on deep clay-loam soils where a system of nearly clean cultivation was used, plowing in large amounts of organic matter and fertilizing liberally with commercial fertilizer. Many growers were placing a vegetable mulch directly under the trees, but cultivating and raising summer cover crops between the rows.

Dr. Felix Löhnis, of the Bureau of Plant Industry, informs the writers that a permanent organic mulch is often employed in the culture of fruit trees in Germany, especially along the roadsides. Leaves, straw, manure, and other organic material are used for this purpose. Coarse peat is also extensively used as a mulching material in districts where it is available.

THE MULCHED BASIN.

In 1913 an opportunity was presented to lay out an experimental tract in a commercial orange grove at Sunny Mountain, near Riverside, Cal., to test further the effect of mulching without cultivation. At this time it was decided to combine mulching with a basin method of irrigation, and accordingly each tree in the section of the grove selected was basined by throwing up dikes 6 to 8 inches high midway between the tree rows in both directions, so that each dike formed a

common division bank of two basins.[1] These square basins were mulched with manure in 1913, and in 1914 they received another mulching of manure (25 to 30 cubic feet per tree) and about 75 pounds of barley straw on top of the manure. In the summer of 1915, each basin received 1½ bales of damaged alfalfa hay.

The experiment included three rows of 16 trees each, making 48 trees in all, or approximately one-half acre. The irrigation water was applied by turning the water into the upper basin of each row separately and allowing it to overflow into the next basin below, and so down the entire row. This method of irrigation was found, however, to be unsuitable to the deep sandy loam soil of this tract. The upper basins were under water too long a time before the lower basins were irrigated, and the water at the upper end of the row penetrated the subsoil below the zone occupied by the principal feeding roots of the trees, resulting in waste. In order to exercise both control and economy of irrigation water, it is necessary to run a furrow down the entire length of the row just outside the basins, so that each basin can be irrigated separately. This procedure was subsequently adopted and is the one usually followed by growers who are installing mulched basins on a commercial scale.

MOISTURE DETERMINATIONS IN THE SUNNY MOUNTAIN GROVE.

At intervals during 1914 duplicate soil samples were taken to a depth of 7 feet in two basins near the upper end of the middle row of basins, and similar samples were taken in two basins near the lower end of the same row, the two outside basined rows being considered as guard rows. Similarly, duplicate samples were taken in the furrow-irrigated part of the grove two tree rows distant from the basined tract, the trees selected for sampling being opposite the basined trees sampled.

In Table I are given the results of moisture determinations made in this experimental tract during the seasons of 1914 and 1915. In 1914 the total moisture averaged about 3.7 per cent higher in the basins than in the check. The moisture available for growth in the first 3 feet of soil in the basins also averaged 3.8 per cent higher than in the check, being an equivalent of approximately 4 miner's inches per acre flowing 24 hours. It will also be noticed (sec. C) that while the first 3 feet of soil under the basins never dried down to the wilting coefficient, the first 3 feet of soil in the check dried out below that percentage three times during the two years, and at four other

[1] While the mulched basin was developed independently by the writers, we have since learned that Mr. J. R. Hodges installed several mulched basins in a grove at Covina, Cal., at an earlier date (1911). So far as the writers know, this was the first use of the system.

periods during the two seasons the wilting coefficient was nearly reached. In other words, the trees in the check were wilted three times during the two summer seasons, while the trees in the basins never wilted. It will be seen from a comparison of sections C and D that this wilting took place with available moisture in the fourth foot of soil.

TABLE I.—*Average percentages of total and available soil moisture in the Sunny Mountain grove, California, in 1914 and 1915.*

[NOTE.—A miner's inch of water flowing 24 hours will increase the moisture content of an acre of soil approximately 1 per cent to a depth of 3 feet.]

Soil treatment,[1] 1914.	July 7.	Aug. 1.	Before irrigation, Aug. 15.	Sept. 2.	Before irrigation, Sept. 21.	After irrigation.		Before irrigation, Nov. 30.	Average for season.
						Oct. 6.	Nov. 4.		
A.—Total in the first 3 feet:									
Mulched	9.4	12.2	8.9	12.9	8.2	15.2	18.8	11.1	12.1
Cultivated	5.7	7.7	5.9	8.9	5.5	11.3	14.6	6.5	8.3
B.—Total in the second 3 feet:									
Mulched	10.8	11.3	10.4	9.9	10.1	11.9	15.9	11.0	11.3
Cultivated	8.6	9.1	8.9	9.2	8.3	7.9	11.3	7.9	7.7
C.—Available in the first 3 feet:									
Mulched	2.6	3.2	2.5	6.2	1.7	8.5	12.1	4.7	5.2
Cultivated	2.0	1.0	.6	2.6	—.6	3.2	8.4	.6	1.5
D.—Available in the second 3 feet:									
Mulched	4.2	4.2	4.2	3.4	3.6	5.2	9.3	4.8	4.9
Cultivated	1.1	2.4	2.6	2.5	2.0	2.5	5.3	1.8	2.5

Soil treatment,[1] 1915.	Dates of sampling before and after irrigation.											Average for season.
	Before, Apr. 9.	After, Apr. 22.	Before, June 2.	After, June 15.	Before, July 10.	After, July 19.	Before, Aug. 6.	After, Aug. 23.	Before Sept. 25.	After, Oct. 2.	Before, Oct. 30.	
A.—Total in the first 3 feet:												
Mulched	8.8	17.8	9.5	11.8	8.7	14.4	9.4	14.7	9.1	13.9	9.8	11.6
Cultivated	7.2	15.1	8.6	11.2	5.9	10.4	5.6	9.9	5.0	10.9	4.3	8.6
B.—Total in the second 3 feet:												
Mulched	10.6	12.8	10.4	12.2	10.0	11.5	11.0	11.5	10.1	11.7	10.4	11.1
Cultivated	6.8	11.5	10.0	10.3	9.6	9.8	9.0	9.0	7.4	8.7	7.3	9.1
C.—Available in the first 3 feet:												
Mulched	2.7	10.9	2.8	7.8	2.7	7.8	2.9	8.6	3.1	7.2	3.6	5.4
Cultivated	1.8	9.1	2.5	5.2	.7	3.8	.5	4.4	—.6	5.5	—1.2	2.9
D.—Available in the second 3 feet:												
Mulched	4.6	6.6	3.8	6.0	4.9	4.2	5.1	5.7	3.8	5.8	4.7	5.0
Cultivated	2.6	5.3	3.3	4.6	3.8	3.4	4.8	2.8	2.3	2.8	1.0	3.3

[1] The mulched treatments were with basin irrigation: the cultivated, with furrow irrigation.

SOIL-MOISTURE MEASUREMENTS IN BASINS, UNDER COVER CROPS, AND UNDER A SOIL MULCH IN THE VIVIENDA GROVE.

In the spring of 1915 a more extended series of experiments was started in an orange grove on sandy loam soil in the Vivienda tract, near Riverside. This soil is a little heavier than that of the Sunny Mountain grove.

The treatments included (1) spreading manure broadcast in the irrigated space between the tree rows and disking it in; (2) burying the manure in a circular trench 18 inches wide and 12 inches deep, located under the drip of the tree; (3) applying the manure as a surface mulch in the basin, which was approximately 15 feet in diameter, with the tree in the center; (4) trenches containing alfalfa in place of manure; (5) basins mulched with alfalfa in place of manure; (6) sweet clover as an irrigated cover crop between the tree rows; (7) barley as an irrigated cover crop; and (8) the usual disk cultivation and furrow irrigation as a check. The treatments were also repeated with the addition per tree of about 100 pounds of flue dust from the neighboring cement works, having the following composition (analysis by J. F. Breazeale):

	Per cent.
Calcium carbonate	53.40
Calcium oxid	13.16
Calcium sulphate	8.89
Phosphoric acid (P_2O_5)	.18
Potash (K_2O)	.95
Insoluble (in dilute HCl)	13.73

Twenty cubic feet of manure per tree were used in each of the manure experiments, and one bale of alfalfa per tree (about 125 pounds) was used in each experiment with alfalfa. A row of orange trees (about 48 trees) was used for each treatment, and each alternate row was left untreated as a guard.

TABLE II.—*Average percentages of total soil moisture to a depth of 3 feet in the Vivienda grove, California, in 1915.*

Soil treatment.	Dates of sampling before and after irrigation.											
	After, June 7.	Before, June 23.	After, June 26.	Before, July 16.	After, July 23.	Before, Aug. 9.	After, Aug. 23.	Before, Sept. 4.	After, Sept. 18.	Before, Oct. 4.	After, Oct. 11.	Before, Oct. 30.
Manure:												
Surface disked	12.2	7.9	14.2	7.4	14.0	7.1	9.7	7.4	(1)	.....	.....	.....
Same, plus lime	11.3	8.9	14.8	8.0	13.1	8.2	8.5	6.7	(1)	.....	.....	.....
Trenched	12.8	7.5	11.7	7.4	6.5	3.3	4.8	6.6	(1)	.....	.....	.....
In basins	12.9	9.0	12.9	9.2	11.6	8.5	12.2	8.1	12.3	7.8	12.8	6.3
Same, plus lime	.....	10.0	14.4	9.0	12.8	9.2	14.8	9.4	13.7	7.8	14.1	8.6
Alfalfa:												
Trenched	14.0	9.2	14.8	7.5	8.7	3.4	3.4	3.0	(1)	.....	.....	.....
In basins	12.4	9.7	12.2	8.7	11.5	8.5	11.5	7.8	11.7	6.8	14.0	6.2
Same, plus lime	.....	10.6	13.8	10.4	12.8	10.3	13.5	9.8	13.9	9.7	12.3	9.7
Sweet clover:												
Cover crop	13.1	6.7	13.9	4.8	15.1	6.9	(1)	.....	.....	.....	.....	.....
Same, plus lime	11.3	6.0	13.5	4.9	14.4	5.3	(1)	.....	.....	.....	.....	.....
Barley:												
Cover crop	12.2	6.7	14.2	5.7	(1)	.....	.....	.....	.....	.....	.....	.....
Same, plus lime	11.7	5.9	13.9	5.6	.....	.....	.....	.....	.....	.....	.....	.....
Disk cultivated	12.5	8.5	14.9	7.5	14.2	6.2	8.8	5.5	(1)	.....	.....	.....
Same, plus lime	12.0	8.5	14.5	7.7	13.1	5.7	7.9	4.7	(1)	.....	.....	.....

[1] Basined.

Table II gives the percentage of total moisture found in the soil under the various treatments. The trees in the trenching experiments were irrigated by running a furrow over the trenches, the assumption being that the water would follow the trench encircling the tree base. The basins were irrigated separately from a furrow along the sides, and the cover crops and disk-cultivated tree rows (including treatments 1, 2, and 8) were irrigated by furrows in the usual manner.

The trenches did not take up much water after the first two irrigations. The soil samples were taken directly in the trench, but 90° from the point of contact of the trench with the irrigation furrow, so that to reach the point of sampling the water would have had to move about 7 feet in the trench. These trenched trees were later basined, as they were not being properly irrigated, owing to the packing and decomposition of the organic matter in the trenches.

The barley did not make a strong growth and when nearly mature was from 18 to 20 inches high. It was disked into the soil in the latter part of July. The sweet clover was at first slow in growth, but by the middle of August it was 2 to 3 feet high. It was then disked in and the trees basined.

The results in Table II show that the use of the summer cover crops, especially sweet clover, resulted in a marked reduction of the water content of the soil compared with the other treatments. With the limited quantity of water available for irrigation in this district it is not practicable to maintain a suitable supply of organic matter in the soil by growing summer crops. The trees grown in conjunction with a cover crop in these trials also showed less new growth during the season than the trees under the other treatments, and the leaves were lighter in color. The cover crop, with its fine root system, secures so much of the water that the orange trees, which have a relatively coarse root system unprovided with root hairs, are bound to suffer.

The effect of the different treatments in conserving the growth water [1] is shown in Table III, which gives the percentage of available moisture to a depth of 3 feet before irrigation, this being the critical moisture period. The basin treatment was most effective in the conservation of moisture, the cultivated rows were next best, and culti-

[1] It is well known that a crop can not remove all the moisture from the soil in which it is growing. The percentage remaining at the time the crop wilts varies greatly with the soil type. The wilting coefficient of a soil is defined as the moisture content of the soil (expressed as a percentage of the dry weight) at the time when the leaves of the plant growing in that soil first undergo a permanent reduction in their moisture content as the result of a deficiency in the soil-moisture supply. By a permanent reduction is meant a condition from which the leaves can not recover in an approximately saturated atmosphere without the addition of water to the soil. The water in a soil in excess of its wilting coefficient is called the "growth water;" that is, it is the portion available for the growth of plants.

vation with a surface application of manure disked in appeared to be slightly more effective than cultivation without manure. The lower moisture content of the soil where lime was added is attributable to the fact that the lime was used on the lower ends of the rows and also to the fact that the slope of the land was slightly greater at the lower end of the tract, so that the lime treatments received less water. Incidentally, this brings out another important advantage of the basin system, namely, that all trees may be given the same amount of water regardless of the physiography of the grove.

TABLE III.—*Average percentages of available soil moisture to a depth of 3 feet, before and after irrigation, in the Vivienda grove, California, in 1915.*

[NOTE.—Minus signs indicate that the moisture content was reduced below the wilting coefficient.]

Soil treatment.	Before irrigation.							After irrigation.					
	June 23.	July 16.	Aug. 9.	Sept. 4.	Oct. 4.	Oct. 30.	Average.	June 6.	June 26.	July 23.	Aug. 23.	Sept. 18.	Oct. 11.
Manure:													
Surface disked	3.3	2.7	1.9	2.4	(1)	.....	2.6	6.7	8.7	9.0	4.9	(1)	.....
Same, plus lime	3.6	3.0	2.5	1.1	(1)	.....	2.6	5.4	8.8	7.6	2.7	(1)	.....
Trenched	2.5	2.2	−2.1	1.1	(1)	.....	.9	7.4	6.1	1.4	− .6	(1)	.....
In basins	4.1	4.1	3.3	2.9	2.9	1.4	3.1	7.2	7.2	6.5	6.6	6.8	7.2
Same, plus lime	4.3	3.4	3.4	4.0	2.4	3.0	3.4	.....	8.4	6.9	8.5	7.8	7.9
Alfalfa:													
Trenched	4.1	2.4	−2.0	−2.4	(1)	.....	.5	8.2	9.0	3.4	−2.0	(1)	.....
In basins	4.2	2.8	2.4	2.1	1.6	.8	2.3	6.1	6.2	6.0	5.8	6.0	7.7
Same, plus lime	4.5	4.3	4.0	4.1	4.1	3.9	4.2	.....	7.5	6.7	7.5	7.5	6.4
Sweet clover:													
Cover crop	1.8	.4	1.1	(1)	.....	.....	1.1	6.9	8.1	9.7	(1)	.....	.....
Same, plus lime	.4	−2.4	− .7	(1)	.....	.....	− .9	4.8	7.2	8.2	(1)	.....	.....
Barley:													
Cover crop	1.5	2.7	(1)	.....	.....	.....	2.1	6.4	8.5	(1)	.....	.....	.....
Same, plus lime	.5	.2	(1)	.....	.....	.....	.4	5.4	7.5	(1)	.....	.....	.....
Disk cultivated	3.4	2.4	.7	− .3	(1)	.....	1.6	7.1	9.1	8.8	3.0	(1)	.....
Same, plus lime	2.9	1.9	− .3	− .8	(1)	.....	.9	5.7	8.3	7.1	2.7	(1)	.....

[1] Basined.

BASIN AND COVER-CROP EXPERIMENTS IN THE VICTORIA GROVE.

Another series of experiments was also begun in the spring of 1915 on the Victoria tract, near Riverside, Cal., the soil being a red-clay loam with granite rock 3 to 4 feet below the surface. The upper layer of this granite to the depth of a few inches is sufficiently decomposed to be removed with a soil tube, but below this the rock is very hard.

The treatments in this grove, which were practically the same as those just discussed for the Vivienda grove, are given in the first column in Table IV,[1] which shows the average moisture content to a depth of 3 feet. The moisture available for growth before and after each irrigation is shown in Table V.

[1] The check row given in Table IV was not cultivated, and conditions were such that another row for a cultivation test was not available.

TABLE IV.—*Average total percentages of soil moisture to a depth of 3 feet in the Victoria grove, California, in 1915.*

[NOTE.—The first four treatments were not irrigated between April 22 and June 10. The last six treatments were irrigated on May 20.]

Soil treatment.	Dates of sampling before and after irrigation.									
	After, Apr. 22.	Before, June 10.	After, June 22.	Before, July 12.	After, July 26.	Before, Aug. 12.	After, Aug. 25.	Before, Sept. 13.	After, Sept. 17.	Before, Oct. 12.
Alfalfa:										
In basins	17.2	12.8	14.5	10.6	15.0	11.9	15.7	10.5	14.5	11.1
Same, plus lime	17.9	12.5	15.7	11.1	18.4	11.7	17.7	12.0	17.5	12.5
Manure:										
In basins	16.4	8.9	13.1	9.2	17.8	11.8	17.4	10.3	17.1	11.9
Same, plus lime	17.7	9.9	12.9	10.1	17.7	12.0	16.9	11.1	19.9	12.8
Sweet clover:										
Cover crop	.....	13.4	14.6	7.0	10.5	5.3	(1)	.....	.....	.....
Same, plus lime	.....	13.1	17.6	8.0	10.2	5.3	(1)	.....	.....	.....
Barley:										
Cover crop	.....	11.3	10.4	7.4	(1)	.....	.....	.....	.....	.....
Same, plus lime	.....	11.0	10.2	5.9	(1)	.....	.....	.....	.....	.....
Uncultivated	.....	14.5	14.3	9.0	9.6	6.3	15.3	8.0	(1)	.....
Same, plus lime	.....	13.4	11.6	9.3	11.9	8.2	13.7	9.8	(1)	.....

[1] Basined.

It is apparent from Table IV that the greatest reduction in moisture took place under the cover crops, the loss being greater than from the uncultivated row. This is brought out more clearly in Table V, which gives the amount of available moisture in the surface 3 feet of soil before irrigation, the critical moisture period. This table shows that the mulched-basin system is the only one that retained available moisture at all times. In all the other treatments the moisture content at some time during the summer was reduced below the wilting coefficient. This deficiency in the moisture supply in the case of the cover-crop tests was also shown by the appearance of the trees, which wilted badly during the summer before the irrigation periods came around.

TABLE V.—*Average percentages of available soil moisture to a depth of 3 feet, before and after monthly irrigations, in the Victoria grove, California, in 1915.*

Soil treatments.	Before monthly irrigations.						After monthly irrigations.				
	June 10.[1]	July 12.	Aug. 13.	Sept. 13.	Oct. 12.	Average.	Apr. 22.	June 22.	July 26.	Aug. 25.	Sept. 17.
Alfalfa:											
In basins	4.7	2.2	3.1	1.8	2.2	2.8	7.8	5.7	6.2	7.4	5.8
Same, plus lime	4.4	2.9	3.3	3.8	4.1	3.7	9.0	7.4	9.7	9.7	9.0
Manure:											
In basins	.1	.9	3.1	1.5	3.2	1.8	6.5	4.2	8.5	9.1	8.3
Same, plus lime	.8	1.1	2.8	2.0	3.3	2.0	8.0	3.5	8.0	8.1	10.4
Sweet clover:											
Cover crop	5.0	−1.0	−2.4	(2)	.....	.5	.....	6.2	1.9	(2)	.....
Same, plus lime	4.5	− .4	−3.0	(2)	.....	.4	.....	8.9	1.5	(2)	.....
Barley:											
Cover crop	3.3	− .8	(2)	.....	.....	1.3	.....	2.2	(2)	.....	.....
Same, plus lime	3.4	−2.6	(2)	.....	.....	.4	.....	1.4	(2)	.....	.....
Uncultivated	5.8	.4	−2.0	− .7	(2)	.9	.....	5.7	1.1	6.7	(2)
Same, plus lime	4.3	.6	.7	.9	(2)	1.6	.....	2.4	3.0	5.1	(2)

[1] The last previous irrigation of basins was given on April 22; other treatments about May 20.
[2] Basined.

FURROW IRRIGATION OFTEN NOT ADEQUATE.

The furrow system of irrigation often fails to provide the moisture necessary for good growing conditions for orange trees in the heavier types of soil. This was strikingly shown during the season of 1915, many orange groves wilting between irrigations. At one time during the summer a grove adjoining the Victoria grove showed wilting for several days before irrigation. Soil samples were taken at the time to determine the percentage of moisture present. The results are shown in Table VI, the moisture-determination figures representing the average moisture content to a depth of 3 feet of soil.

TABLE VI.—*Moisture conditions under wilted orange trees.*

Condition of leaves.	Moisture equivalent.	Wilting coefficient.	Average moisture.	
			In soil.	Available.
			Per cent.	*Per cent.*
All leaves on tree badly wilted	15.6	8.5	6.9	−1.6
Leaves on top third of tree badly wilted, lower two-thirds not wilted	15.1	8.2	7.1	− .1

The moisture determinations include the dry surface soil, which through surface evaporation dries out to about one-half the wilting coefficient, so that the average moisture content of the 3-foot section is about nine-tenths that of the soil actually occupied by the tree roots. The second tree mentioned in Table VI had been wilted for several days preceding the sampling. These observations on heavy soil and similar observations on light soil show that the wilting coefficient determined indirectly from the moisture equivalent of a soil agrees satisfactorily with direct determinations made in the groves.

LATERAL MOVEMENT OF SOIL MOISTURE VERY SLIGHT.

The lateral movement of moisture in the heavy soils of the Victoria tract is very slight. After an irrigation considered sufficient to last about 28 days, the moisture was found to have penetrated laterally only about 18 inches from the irrigation furrow. In other words, there is practically no lateral movement of water toward the tree, the feeding roots being confined to the soil below the irrigation furrows.

The lateral movement of water was also found to be very slight in a basined grove at Redlands located on the same type of soil as the Victoria grove just discussed. Soil samples were taken on May 26, before the first spring irrigation, and the day after the grove was irrigated samples were again taken within a few inches of the first samples. Alfalfa was being grown in the furrows between the

basins to supply mulching material. The basins in this grove were small and were separated in the tree row by spaces about 4 feet in width. These spaces between the basins were bare and unirrigated, the usual practice. The results of the moisture determinations presented in Table VII show no lateral movement of soil moisture from the basins into these spaces during irrigation.

TABLE VII.—*Available soil moisture before and after irrigation in an orange grove having alfalfa growing in the furrow rows at Redlands, Cal.*

Depth.	Available moisture before irrigation (per cent).			Available moisture after irrigation (per cent).		
	In basins.	In alfalfa furrow rows.	Between basins in tree rows, about 2 feet from basins.	In basins.	In alfalfa furrow rows.	Between basins in tree rows, about 2 feet from basins.
First foot	4.2	−1.4	0.9	7.4	4.9	−0.7
Second foot	4.8	− .6	1.8	6.4	.8	1.1
Third foot	5.1	.1	2.1	5.5	1.0	2.4
Fourth foot	4.3	.4	2.9	4.9	1.9	3.1
Average	4.6	− .4	1.9	5.6	2.2	1.5

SUMMER COVER CROPS IN ORANGE GROVES NOT PRACTICABLE WITHOUT AN INCREASED WATER SUPPLY.

The moisture conditions in the alfalfa furrow rows as shown in Table VII are quite typical of conditions found in other orange groves with alfalfa growing between the trees. In 1914, soil samples were taken in three groves of this kind after irrigation, and the moisture had penetrated only from 10 to 30 inches after a two or three days' run of water. The large amount of water removed by such crops and the bad effect on the orange trees of the competition with the cover crop have already been mentioned in connection with the experiments in the Victoria and Vivienda groves. With the amount of water usually available for irrigation in these districts (1 miner's inch to 5 acres), no summer cover crop of any kind can be grown in citrus groves in the areas studied without causing deterioration of the trees. Instances were found where summer crops, such as buckwheat and sweet clover, were grown quite regularly, but in these cases there was plenty of water available for both trees and cover crop.

ORGANIC MULCHES MORE EFFECTIVE THAN SOIL MULCHES IN CONSERVING WATER.

Four cylindrical cans 24 inches high and 18 inches in diameter were filled with soil from the Victoria grove on June 25. The soil in the different cans was treated as follows: (1) Surface soil kept

mulched, (2) surface soil left undisturbed, (3) seeded to barley, (4) covered with about 2 inches of alfalfa mulch. The soil contained 19.2 per cent of moisture when the cans were filled. The cans were weighed from time to time to determine the moisture loss, but only the final results need be given here. On August 3, 38 days after the initial weighing, the moisture content of the soil in the different cans was as follows: (1) Surface soil mulched, 14 per cent; (2) surface left undisturbed, 10.1 per cent; (3) seeded to barley, 3.1 per cent; (4) mulched with alfalfa, 18 per cent. The soil seeded to barley had reached the wilting coefficient by July 16, 21 days after the seed was planted.

These results show the relative effectiveness of a soil mulch and an alfalfa mulch in retaining moisture. The soil under the alfalfa mulch had lost but 1.2 per cent of moisture, while the soil under the dust mulch had lost 4 per cent, or over three times as much as the alfalfa-covered soil. The soil mulch in this test was, furthermore, kept in a much more effective condition than is practicable in a grove.

EFFECT OF BASINING ON TREE GROWTH.

THE SUNNY MOUNTAIN GROVE.

On the light soil of the Sunny Mountain experimental grove it was nearly a year before any very noticeable change occurred in the appearance of the mulched trees, but during the autumn of 1914 there was a distinct advance in the new growth on the trees in the basins as compared with the check trees.

The grove was badly infested with scale, for which it was fumigated in the fall of 1914, at a time when the new growth on the basined trees was well advanced. The basined trees, on account of the larger amount of new growth, were injured more by the fumigation than the check trees, but the trees soon recovered and again grew faster than the check trees. The beneficial effect of the mulched-basin treatment was also plainly in evidence on the untreated rows of trees immediately adjoining the experimental tract, showing that the root systems extend laterally to adjoining tree rows when conditions are favorable.

THE VICTORIA GROVE.

The portion of the grove used for these experiments had been previously used as an experimental plat and had received sodium nitrate only as a fertilizer for four years. This experiment was terminated in 1913, and the plat was manured in 1914. The trees were in an unthrifty condition in 1914 and 67 per cent of the leaves were mottled. The trees were heavily pruned in the winter of 1914–15, so that the

mottle-leaf was not so conspicuous as it had been previous to pruning, but the trees had made no visible response to the change in treatment.

A row of trees was basined in the latter part of April, and by the latter part of July, a little over three months, there was a remarkable improvement in the appearance of the basined row compared with the check trees. There was a vigorous new growth of leaves, which were large and velvety in texture, dark green in color, and almost free from mottling, while the new leaves on the trees in the check row were small and yellowish, more or less mottled, and never developed normally. The accompanying photograph (Pl. I) was taken about the middle of July and shows clearly the improvement in growth and color of the basined trees.

THE VIVIENDA GROVE.

The basined trees in this grove did not respond to the mulched-basin treatment as rapidly as the basined trees in the Victoria grove, but by the fall of 1915 there was a very distinct improvement in the appearance of the basined trees when compared with the check trees.

THE MULCHED BASIN IN RELATION TO SOIL TYPE.

The early response of trees on heavy soils to the mulched-basin treatment appears to be due to the more uniform moisture conditions under the mulch and also to the fact that more available moisture is present in the basins than under the furrow method. The heavy soils of the Victoria groves in general do not take water well, and there is very little lateral movement of water from the irrigation furrows. Soil samples taken 18 inches from a furrow immediately after irrigation frequently showed no increase in moisture due to irrigation. It appears, therefore, that under such a furrow system of irrigation, unless the number of furrows is greatly increased over the usual number, the heavy soils are not thoroughly irrigated, so that a considerable portion of the soil is devoid of available moisture during part of the irrigation season.

On the other hand, sandy loam soils, like those of the Vivienda and Sunny Mountain groves, take water more readily, so that after an irrigation the moisture content of these soils is more nearly uniform and the available moisture is higher than in heavier soils under furrow irrigation. The trees in the groves on the higher soils, therefore, do not suffer so much from lack of water under the furrow method of irrigation as the trees on the heavier soils.

Table VIII shows the available moisture after irrigation in the Vivienda (sandy loam) and Victoria (clay loam) groves. The sandy loam soils show more available moisture after irrigation than the

TWO ROWS OF ORANGE TREES IN THE VICTORIA GROVE IN CALIFORNIA, SHOWING THE EFFECT OF THE MULCHED-BASIN SYSTEM ON MOTTLE-LEAF AFTER THREE MONTHS' TREATMENT.

The left-hand row was under the mulched-basin system, while the right-hand row was furrow irrigated. The two rows at the beginning of the experiment were equally mottled. The light-yellow foliage of the furrow-irrigated row is clearly seen on the right, and the marked improvement of the basined row is shown in the dark foliage on the left. The ridges of the circular basins can be seen at the base of the trees of the left-hand row. The right-hand row is separated by a guard row from the pepper trees shown on the extreme right.

clay-loam soils where cover crops are grown or where the soil is cultivated. On the other hand, under the basin system the heavy soil has a little more available moisture after irrigation than the sandy loam soil.

TABLE VIII.—*Average available soil moisture to a depth of 3 feet in sandy loam (Vivienda grove) and in clay loam (Victoria grove) after irrigation.*

Soil treatments.	Clay loam.	Sandy loam.	Soil treatments.	Clay loam.	Sandy loam.
Manure:	*Per cent.*	*Per cent.*	Sweet clover:	*Per cent.*	*Per cent.*
In basins	7.3	6.9	Cover crop	4.2	8.2
Same, plus lime	7.6	7.9	Same, plus lime	5.2	6.7
Alfalfa:			Barley:		
In basins	6.6	6.0	Cover crop	2.2	7.5
Same, plus lime	8.8	7.3	Same, plus lime	1.4	6.5
			Cultivated	4.0	6.5

Where groves are planted on heavy adobe soils, as is the case with some groves near Whittier, the use of the mulched basins has been found inadvisable. Heavy adobe soil swells when thoroughly moistened, and in this condition is practically impervious to water and to air. In the case of heavy adobe soils (derived from Pierre shale) on the Bellefourche Reclamation Project in South Dakota, it has been observed that the irrigation is effective only so long as the shrinkage cracks are in evidence. The water is distributed through the soil by means of these openings, and when the adobe has swelled sufficiently to close the cracks the soil will take no more water. The use of mulched basins on heavy adobe results in a more nearly uniform moisture condition at the surface and prevents the development of surface cracks. These fissures appear to be essential, or at least desirable, for the proper irrigation and aeration of heavy adobe. On the same ranch near Whittier, Cal., where the difficulty with heavy adobe was encountered, lemon trees on soil of a less pronounced adobe character have shown a most favorable response to the mulched-basin treatment.

EFFECT OF THE MULCHED BASINS ON SOIL CONDITIONS AND ROOT GROWTH.

In all the experiments carried on with mulched basins having an area as large as the spread of the tree, irrigation once a month has been sufficient to maintain a good soil-moisture condition throughout the period between irrigations. The mulch also tends to maintain a moderate and more uniform soil temperature, and in this respect it is aided materially by the location of the irrigated area largely under the tree, where it is shaded by the tree top. The plowsole nearly always present in the furrow and cultivation method of treatment also disappears in the mulched basin, and so far no plowsole or

equivalent crust has been encountered in basins where an adequate organic mulch has been maintained.

The application of an organic mulch to the basins is followed in some districts by a remarkable increase in the number of earthworms. Earthworms are not often seen in orange or lemon groves under clean cultivation, but in the basins in the Riverside district the soil teems with them; a double handful of soil would often be found to contain a dozen or more worms, and the soil is so riddled with their burrows that when the basin around a tree is filled with water a sea of bubbles appears on the water surface, due to the rapid escape of air from the burrows. The air entrapped below a wet soil surface of fine texture presents a serious obstacle to the further penetration of water unless the soil contains cracks or openings, such as the burrows of earthworms, that are too large to be sealed by the capillary water films. The worms thus appear to have some effect in promoting aeration, and they surely facilitate to a marked degree the penetration of water into the soil. The beneficial effect of the presence of earthworms in the soil has been emphasized by Darwin.

The vigorous root growth taking place in the surface soil under the mulch is very marked in the mulched basins. In the system of dry-soil mulching there is, of course, no root growth in the mulch, and quite often there is very little root growth even to a depth of 8 to 10 inches, owing to the presence of plowsole. Under the mulch in the basins the ground is full of rootlets. The roots have not been observed to penetrate the mulch and are usually not found even in the very rich surface inch of soil. It can readily be seen, however, that any fertilizer applied in these basins soon comes in contact with the root system through the downward movement of the irrigation water and without the necessity of any mechanical incorporation of this material with the soil by cultivation.

Since the mass of fine feeding roots is so near the surface of the soil in the basins, it is absolutely necessary to maintain a mulch that will thoroughly protect this root system, especially during the hot season of the year. A crusting of the surface soil in the basins due to the lack of sufficient mulching material would be very detrimental to the root system.

FRUIT SETTING AND TREE GROWTH AS INFLUENCED BY THE MULCHING MATERIAL.

SUNNY MOUNTAIN TRACT.

There was no appreciable difference in the number of fruits picked in the spring of 1914 from the basined trees and the check trees in the Sunny Mountain grove. This shows the uniformity of the two plats,

the fruit having been set in the spring of 1913 before the mulch was applied. In the spring of 1915, however, there was a much heavier set of flowers on the trees basined than on the check trees; but, owing apparently to the effect of cold weather after the fruit had begun to set, the entire district suffered considerably from a heavy drop of the young orange fruits and the unset flowers. On August 23, 1915, a careful count was made of the number of fruits on the trees under the two systems. The fruits at that time were of good size. The number of fruits on the check trees averaged 116 per tree, while the number of fruits on the basined trees averaged 281 per tree, or 2.4 times as many as on the check trees. The quality of the fruit on the basined trees during this season was also superior to that on the check trees, and the fruits were larger and more nearly uniform in size.

VICTORIA TRACT.

In April, 1915, one row of 33 orange trees in this tract was basined and mulched, one-half of the trees being mulched with alfalfa at the rate of about 1½ bales, or 185 pounds, per basin, and the remainder with cow manure of good quality at the rate of about 20 cubic feet per basin. Some of the basins in each treatment also received 200 pounds of lime, but as no effect of the lime was observable, the discussion will be confined to the mulching materials alone. The basins were circular in form and about 15 feet in diameter, covering an area of about 170 square feet.

There was practically no fruit on these trees in 1915, owing to general deterioration and to a severe scale attack and severe top pruning in the season of 1914–15. On August 12, 1916, 16 months after the installation of the basins, the oranges on each tree were counted. The trees mulched with alfalfa averaged 483 oranges per tree and those mulched with manure 242 oranges per tree. In other words, the trees mulched with alfalfa carried twice as much fruit as those mulched with manure.

The alfalfa mulch was applied to the first eight and the last nine trees in the row and the manure mulch to the intermediate trees. Both ends of the row responded similarly to the alfalfa mulch, not only in fruit setting but in the density and dark color of the foliage as well, the trees showing distinctly the boundary between the two treatments.

At the time the above row (No. 3 in the grove) was basined and mulched an adjoining row (No. 2) was left untreated, and this was furrow irrigated in the usual manner but not cultivated. By August, 1915, row No. 2 was looking so bad that it was decided to basin it. The basins installed were small (about 8 feet in diameter, or 50 to

60 square feet in area) and were mulched with a mixture of hay of different kinds. The trees improved in appearance, but on August 12, 1916, when the counts were made, they were still far from being in as good condition as the trees in row No. 3. On that date the average number of oranges per tree in row No. 2 was 182.

At the time that row No. 3 was basined and mulched the rest of the grove was treated likewise, except that smaller basins, 70 to 80 square feet in area, were installed. These trees improved greatly as compared with trees in certain other adjoining rows which were furrow irrigated in the usual way, but they have not yet come up to row No. 3 either in the appearance of the foliage or in fruit bearing, showing that the larger basins are much more effective.

EUREKA TRACT.

A test of the relative value of different mulching materials was begun in this tract in October, 1915, on a block of 60 navel-orange trees. The mulching material used included alfalfa, bean straw, bur clover, sweet clover, barley hay, stable manure, and pine shavings. The basins were about 10 by 12 feet in dimensions. Approximately 125 pounds of mulching material was applied to each basin, except in the case of bean straw, which on account of its scarcity at the time was applied at the rate of 75 pounds per basin. The manure was applied at the rate of about 15 cubic feet per basin. Various commercial fertilizers were also applied to some of the trees, but the effect of these substances was not in evidence at the time the oranges were counted.

In August, 1916, 10 months after the mulch was applied, the number of oranges on each tree was determined by counting. Records of the yields of the individual trees in this block had also been kept for the preceding six years by the Office of Horticultural and Pomological Investigations of the Bureau of Plant Industry, which afforded an excellent basis for establishing the relative productiveness of the different trees under the same treatment. To make the results of the mulching experiments directly comparable, the mean yield of each group of trees in 1916 was corrected by dividing the observed count by the ratio of the average productiveness of that group during the preceding six years to that of the whole block for the same period. This eliminates the influence of high or low performance trees. The results of the counts are given in Table IX, together with the relative yield under the various mulching treatments.

TABLE IX.—*Relative yields of oranges with different mulching materials in the basins.*

Mulching material.	Number of trees.	Yield in 1916.		
		Average number of oranges per tree.	Corrected on basis of previous performance of trees.	Percentage of mean yield of whole block.
Alfalfa hay	12	550	532	150
Bean straw	9	463	460	130
Manure	9	358	358	101
Barley hay	10	280	313	89
Sweet clover	9	314	305	86
Bur clover	5	302	300	85
Pine shavings	6	224	217	61

It is evident from Table IX that the mulching materials tested differ greatly in value. The highest yield of fruit was obtained when alfalfa was used as a mulch, while the bean straw and manure rank next. The quantity of bean straw used, however, was not sufficient to make an effective mulch, and it seems probable that alfalfa and bean straw are of approximately equal value for mulching purposes. The other legumes were much less beneficial than alfalfa and bean straw. The lowest yield was obtained where pine shavings were employed as a mulch. This material effectively protected the basins from evaporation, so that the beneficial action of the other mulching material is clearly attributable to the organic products from the decomposing mulch which are carried into the soil with the irrigation water.

The average number of oranges on the trees basined and mulched with alfalfa hay was 8 per cent greater than the average yield from these same trees during the preceding six years under furrow irrigation and clean cultivation. The other treatments all show a falling off in yield compared with the average yield of the preceding six years. Up to the time the basins were established, the trees had been irrigated by means of furrows between the tree rows. When the basins were established under the trees, the irrigation between the tree rows was discontinued. The excavations of the basins to a depth of 6 to 8 inches necessarily destroyed some of the small feeding roots, and this fact, combined with the discontinuance of the irrigation between the tree rows, forced the trees to establish a new root system during the time that the fruit buds of the 1916 crop were being developed. A decrease in yield accompanied in most instances the redistribution of the root system, and this fact emphasizes the desirability of a gradual transition to the basin system if the entire surface is not basined. Irrigation and cultivation between the basins for the first year following the installation of the basins would help

the trees to reestablish their root systems without checking the growth.

The foliage of the trees mulched with alfalfa and bean straw was much denser and darker in color than that of the trees mulched with barley and pine shavings, the latter trees being off color. The trees mulched with sweet clover, bur clover, and manure were intermediate in color and density of foliage.

While the values of the different mulching materials used in this experiment can not be considered to be accurately represented by the results shown in Table IX, their probable relative value is indicated. In view of the corroborative results obtained in the Victoria tract it would appear that alfalfa is decidedly more valuable for mulching purposes than manure. It also appears from these tests that 150 pounds of alfalfa or 15 to 20 cubic feet of manure when applied to an area of about 150 to 170 square feet will provide sufficient mulching material to last one year and maintain an effective mulch during that period.

REDLANDS TRACT.

A further comparison of the mulched-basin method with furrow irrigation is afforded by a mulched grove near Redlands. This was planted at the same time and with the same stock as an adjoining grove, and the two received uniform treatment for a time, but for a number of years they have been handled independently. In 1913 a grove of 8 acres was basined by the owner and mulched with alfalfa. The basins were small, scarcely including the drip of the trees. Owing to the slope of the land, two basins were necessary for each tree. The furrow rows were seeded to alfalfa at the time the basins were made, for the purpose of supplying mulching material. The amount of alfalfa produced, however, was not even sufficient to maintain a mulch in the small basins, and in the fall of 1915 the alfalfa was plowed up. The seeding of the furrow rows to alfalfa undoubtedly checked the growth of the trees somewhat by limiting the moisture supply. Moisture determinations made immediately after irrigation where alfalfa was growing showed that the irrigation water penetrated only about a foot below the bottom of the furrows.

A 10-acre grove adjoining the 8-acre basined grove has throughout been furrow irrigated and cultivated in the usual manner.

While the basins were established in the 8-acre tract in 1913, their effect on the set and yield of fruit would not be seen until the following year. The average yield of this tract in 1911 and 1913 (1912 being excluded on account of the freeze) was 4.9 boxes per tree, compared with 3.2 boxes per tree on the 10-acre tract.

The average annual yield per tree of the 8-acre tract since the basins were installed has been 5.5 boxes per tree,[1] while the average annual yield of the unbasined trees during the same period has been 3.2 boxes per tree, the same as during the preceding period.

It is not possible to differentiate sharply in this case between the effect of mulching and other factors which led to higher yields from the 8-acre tract previous to mulching. Assuming the 10-acre tract to constitute a fair check, the yield of the 8-acre tract has been increased 12 per cent by the installation of the basins.[2]

SIZE OF BASINS.

The basins in the Sunny Mountain experimental tract extended to the middle of the furrow row and included the entire soil surface. This type of basin requires the most mulching material and is consequently the most expensive to maintain. In following this plan it is necessary to restrict the basins between every fifth and sixth row of trees sufficiently to provide a roadway to haul out fruit, bring in the mulching material, and distribute fire pots and oil when frost protection is necessary. With this type of basin all of the soil is irrigated and available for the development of the root system of the tree. If all of this soil is not necessary for an adequate root development, then a restricted basin system may be used. Certainly all of the soil is not utilized to the best advantage in the present system of furrow irrigation, for the soil under the tree during the summer is so dry as to make the development of feeding roots practically impossible. From the marked response and increased vigor of the trees under the basin system in the Victoria and Vivienda experimental tracts, where restricted basins were used, it appears that the basins can be reduced somewhat below the maximum area without detriment to the trees and with a corresponding reduction in the cost of maintenance.

With restricted basins, measuring 10 by 20 feet in a grove planted 20 feet each way, a cover crop can also be grown between the tree rows during the rainy months to supply part of the mulching material. The summer growth on these interrow strips, which without irrigation will necessarily be limited, can also be cut and applied to the basins when sufficient in quantity to justify the labor. If extra water is available, these interstrips may be irrigated and the

[1] This is based upon the yield of only one-half the tract in 1915–16. The remaining portion was seriously damaged through the use of an oil spray for scale in 1915, resulting in a heavy drop of leaves and fruit and reducing the yield of the sprayed portion to less than half that of the unsprayed trees.

[2] The crop on the trees at the present writing (September, 1916) is also much better on the mulched-basin tract than on the adjoining grove, in spite of the fact that the 8-acre tract is badly infested with scale.

yield of mulching material increased. It is not practicable, however, to attempt to provide all of the mulch in this way.

In groves planted on contours the form and size of the basins will necessarily be determined by the slope of the land. In such cases two smaller basins will usually be required for each tree, one above and one below the tree in the row. Even in straight-row planting it will often be found advisable to divide the basin at the tree trunk in order to insure adequate irrigation on both sides of the tree. Special precaution should be taken to prevent the soil forming the dikes from being banked against the trunk of the tree. Lemons appear to be particularly susceptible to bark diseases when through low planting or soil washing the moist soil is brought into contact with the trunk above the graft.

COST OF PREPARING AND MAINTAINING THE BASINS AND THE MULCH.

The initial cost of installing a basin system varies with the soil and with the size of the basins. No exact figures can be given for all the different soil types and basin sizes, but some specific examples can be cited. The cost for labor alone in one grove on a sandy loam soil was about $18 per acre. The basins in this grove were circular and about 8 feet in diameter, and the grove was close planted. The labor cost in other groves on clay-loam soil ranged from $22 to $25 per acre.

The cost of the mulching material varies greatly. At the present writing, manure in carload lots from Los Angeles costs $2.20 per ton delivered on siding in orange districts 50 miles distant. Allowing 15 cubic feet of manure per basin, this would cost approximately 50 cents per tree. One hundred and fifty pounds of alfalfa or bean straw will provide a mulch equivalent to that obtained with 15 cubic feet of manure, and in the experimental plats has given greater returns. The average yield from one block (Victoria grove) of alfalfa-mulched trees was twice that of the manure-mulched trees, while in another block (Eureka grove) the alfalfa-mulched trees carried on the average 50 per cent more fruit than the trees mulched with manure. Barley straw costs less than either alfalfa or bean straw, as a rule, but in the trials here reported it has not proved so desirable a material for use as a mulch, and it contains less nitrogen.

Any mulch lasts well during the summer season, although the under portions undergo decomposition soon after being applied. During the rainy season, however, all kinds of mulching material break up rapidly, and in the course of a year the mulch practically disappears unless a fairly large quantity is used. In general it appears that 150 pounds of alfalfa or its equivalent a year is necessary to maintain a mulch in a basin 150 square feet in area.

The maintenance of the dikes is a small item of expense, and with a furrow along the side of the basins for irrigating each basin separately there should be no upkeep expense for two years at least, and probably the dikes will last longer. It is necessary, however, to use only a small stream of water in filling the basin, especially on land with a steep slope, as otherwise the silt and fine sand brought into the basin will in time fill it, necessitating future excavations, with the loss of a part of the rich soil formed.

The cost of the application of water will probably be greater with the basin system, as it will be necessary to keep a night irrigator on duty during irrigation. On the other hand, there is a marked saving in the quantity of water used and a marked saving through the elimination of teamwork of all kinds in the orchard except for hauling fruit and replenishing the mulching material. The breaking of heavy fruit-bearing branches during cultivation and the injury of fruit from contact with harness or harrow are also avoided.

LIMITATIONS OF THE MULCHED-BASIN SYSTEM.

The mulched basin is not the solution of all the difficulties of citrus culture. It will probably be found less advantageous on sandy or sandy loam soils than on loam or clay-loam soils. It is not suitable for heavy gumbo soils. Some hand labor (hoeing or mowing) will be required to keep the weed growth in the basins under control and to prevent undue loss of moisture from this source.[1] The organic mulch in the basins will also harbor some gophers, although experience so far indicates that the frequent flooding of the basins discourages them from seeking refuge under the mulch. The proximity of the roots to the surface necessitates the maintenance of an effective organic mulch in the basins for the best results. The cost of suitable mulching material will very greatly depend on the location of the groves and in some cases may seem prohibitive. In this connection it must be remembered that the humus content of some citrus groves has been reduced to such a degree that its restoration by some means appears imperative. The efficiency from the nutrition standpoint of the organic material applied to the surface in comparison with the same material plowed under remains to be determined.

The marked response of citrus trees under the mulched-basin system in the experimental tracts justifies its serious consideration by citrus growers. Its final position in the industry can be determined only after it has been thoroughly tested in comparison with other systems in commercial practice.

[1] This plant growth in the basins can, of course, be used to supplement the mulching material.

HUMUS CONTENT OF THE BASINS AND THE CHECK SOILS.

SUNNY MOUNTAIN GROVE.

Determinations of the humus content of the soil in the basined area and in the untreated area to a depth of 3 feet are given in Table X. Determinations of humus are necessarily somewhat inaccurate, owing not only to the variation in sampling but also to the fact that humus, so-called, is an indefinite mixture of organic compounds.[1] The Sunny Mountain grove, so far as known, had been treated uniformly previous to the installation of the mulched basins. Composite samples collected in 1914 indicated that the check area contained slightly more humus than the basined area. In the spring of 1915, however, the surface foot of the basined area was higher in humus, as shown in Table XIII. The humus content of the surface foot of soil below the mulch also increased gradually throughout the summer, while the check area, which received no organic material save that contained in commercial fertilizers, showed practically no change. The increase in humus in the basins is confined practically to the first foot of soil. At lower depths the humus content of the two tracts differs but slightly, decreasing gradually to a depth of 6 feet, as shown by the mean values in Table X. If the humus content of the soil is limited, it is advantageous to have it localized largely in the upper 3 feet of soil, which in most California soils includes the principal feeding roots of citrus trees.

TABLE X.—*Percentage of humus in the first and in the second 3 feet of soil in the Sunny Mountain grove, California, in 1915.*

Depth and date.	Basins near upper end of tract.				Basins near lower end of tract.				Average, both ends of tract.	Furrow system near upper end of tract.				Furrow system near lower end of tract.				Average, both ends of tract.
	First foot.	Second foot.	Third foot.	Average.	First foot.	Second foot.	Third foot.	Average.		First foot.	Second foot.	Third foot.	Average.	First foot.	Second foot.	Third foot.	Average.	
First 3 feet:																		
Apr. 9...	0.52	0.18	0.17	0.29	0.53	0.34	0.21	0.36	0.33	0.37	0.27	0.13	0.26	0.37	0.27	0.14	0.26	0.26
June 15..	.63	.22	.13	.33	.59	.29	.13	.34	.33	.32	.24	.11	.22	.42	.35	.17	.31	.27
July 10..	.72	.26	.10	.36	.63	.25	.16	.35	.35	.42	.18	.10	.23	.29	.42	.22	.31	.27
Aug. 6..	.67	.28	.14	.36	.50	.23	.13	.29	.33	.37	.24	.17	.26	.50	.44	.18	.37	.32
Sept. 21.	.84	.16	.08	.36	.67	.36	.10	.37	.37	.36	.20	.11	.22	.37	.32	.26	.27	.27
Average..	.68	.22	.12	.34	.58	.29	.15	.34	.34	.37	.23	.12	.24	.39	.36	.19	.30	.28

[1] The humus was determined by removing the calcium with 1 per cent hydrochloric acid, extracting with sodium hydroxid, and measuring the intensity of the humus color against a standard humus solution in a colorimeter. The standard solution was freshly made up by weight from uniform dry stock material obtained by extraction with 4 per cent ammonia after treating with 1 per cent hydrochloric acid and washing free from chlorids. The ammonia extract was filtered through a Pasteur-Chamberland filter before evaporating to dryness.

TABLE X.—*Percentage of humus in the first and in the second 3 feet of soil in the Sunny Mountain grove, California, in 1915*—Continued.

Depth and date.	Basins near upper end of tract.				Basins near lower end of tract.				Average, both ends of tract.	Furrow system near upper end of tract.				Furrow system near lower end of tract.				Average, both ends of tract.
	Fourth foot.	Fifth foot.	Sixth foot.	Average.	Fourth foot.	Fifth foot.	Sixth foot.	Average.		Fourth foot.	Fifth foot.	Sixth foot.	Average.	Fourth foot.	Fifth foot.	Sixth foot.	Average.	
Second 3 feet:																		
Apr. 9	0.07	0.05	0.05	0.06	0.12	0.05	0.03	0.07	0.06	0.05	0.02	Tr.	0.02	0.07	0.04	0.03	0.05	0.04
June 15	.09	.04	.03	.05	.06	.03	.03	.04	.05	.05	.03	0.03	.04	.13	.08	.05	.08	.06
July 10	.07	.04	.04	.05	.07	.04	.04	.05	.05	.06	.05	.04	.05	.13	.11	.05	.10	.07
Aug. 6	.12	.05	.05	.07	.08	.06	.04	.06	.07	.07	.05	.04	.05	.18	.09	.08	.12	.08
Sept. 21	.08	.03	.03	.05	.11	.05	.03	.06	.05	.06	.04	.03	.05	.09	.06	.06	.07	.06
Average	.09	.04	.04	.06	.09	.05	.03	.06	.06	.06	.04	.03	.04	.12	.08	.05	.08	.06

VIVIENDA GROVE.

Determinations of the average percentage of humus in the first 3 feet of soil in the Vivienda experimental tract are presented in Table XI. Samples taken in October, about four months after the mulch was applied, showed an appreciable increase in the humus content of the soil in the basins. The mulch was carefully removed before sampling, so that only the soil itself was taken up. The percentage increase in humus was about the same in the basins mulched with manure and with alfalfa.

The plat in which the barley was disked showed a marked increase in humus 50 days after the green cover crop was incorporated with the soil. The changes in humus content were all confined to the surface foot of soil.

TABLE XI.—*Average percentage of soil humus to a depth of 3 feet when various treatments were given in the Vivienda grove, California, in 1915.*

Soil treatment.	June 23.	July 16.	Aug. 9.	Sept. 4.	Oct. 4.	Oct. 30.
Manure:						
Surface disked	0.15	.....	0.16	0.14	(1)	.....
Same, plus lime	.19	.....	.20	.16	(1)	.....
In basins	.15	.....	.12	.15	0.18	0.21
Same, plus lime	.18	.....	.16	.19	.24	.31
Alfalfa:						
In basins	.12	.....	.13	.13	.24	.20
Same, plus lime	.18	.....	.13	.19	.30	.26
Sweet clover:						
Disked in about August 15	.14	.....	.15	.13	(1)	.....
Same, plus lime	.22	.....	.21	.23	(1)	.....
Barley:						
Disked in July 16	.16	0.16	.....	.25	(1)	.....
Same, plus lime	.18	.17	.....	.25	(1)	.....
Disk cultivated	.16	.....	.15	.19	(1)	.....
Same, plus lime	.22	.....	.16	.19	(1)	.....

[1] Basined.

VICTORIA GROVE.

The percentage of humus in the soil in the Victoria grove under the various treatments is shown in Table XII. Here again the humus did not increase perceptibly in the basins until October, 112 days after the initial samples were taken. The low initial humus content in the basins is due in part to the removal of the surface soil in making the basins. The manure and alfalfa were equally effective in increasing the humus percentage up to the time of the last sampling.

TABLE XII.—*Average percentage of soil humus to a depth of 3 feet when various treatments were given in the Victoria grove, California, in 1915.*

Soil treatment.	June 22.	Aug. 13.	Sept. 13.	Oct. 12.
Alfalfa:				
In basins	0.073	0.073	0.075	0.084
Same, plus lime	.134	.106	.147	.155
Manure:				
In basins	.136	.130	.136	.153
Same, plus lime	.150	.112	.139	.160

SUMMARY.

Mottle-leaf of citrus trees is characterized by yellowish spots or blotches on the leaves and by a reduction in the size of the leaves and the density of the foliage. In its advanced stages it results in a marked reduction in yield and in the size and quality of the fruit. No fungus or bacterium has yet been found to be causally associated with this trouble.

Work carried out by the writers in 1914 and reported in another paper showed that half of the mottling in about 120 orange groves in the Riverside, Redlands, Rialto, and Highland districts of California was associated with a low humus content of the soil. Evidence was also secured which indicated that inadequate irrigation might be responsible in part for the development of mottle-leaf.

The present paper is concerned with field experiments relating to the irrigation of oranges and the use of organic fertilizers and deals particularly with a new method of citrus culture, the mulched-basin system, in which low dikes are thrown up so as to form large shallow irrigation basins near each tree, and each basin is heavily mulched with alfalfa hay, bean straw, manure, or some other organic material. The basin makes it possible to supply each tree with water in accordance with its needs, while the water carries with it to the feeding-root system the plant food extracted from the disintegrating mulch.

The system of furrow irrigation and clean cultivation in common use in citrus districts in California tends to promote the formation

of a plowsole, or incipient hardpan, below the surface mulch, varying in thickness from 3 inches to 2 feet; leads to excessive accumulations of soluble plant-food substances, especially nitrates, at the surface of the soil, where they remain until washed down by the winter rains; and fails to conserve the soil moisture sufficiently to prevent the trees from wilting frequently during the summer months.

The mulched-basin system was found to conserve the soil moisture better than any other system of soil treatment compared with it, and none of the basined trees on either light or heavy soils wilted. Under all the other cultural methods employed wilting occurred at some period during the summer on both light and heavy soils.

Available soil moisture below the third foot did not prevent orange trees from wilting if the moisture content in the first 3 feet of soil fell below the wilting coefficient.

With the amount of irrigation water ordinarily available in these districts (1 miner's inch to 4 or 5 acres) cover crops of barley or sweet clover can not be grown during the summer months in groves on either heavy or light soils without causing the wilting of the orange trees.

Circular trenches dug around orange trees, filled with manure or alfalfa and covered with dirt, did not remain open sufficiently after the second irrigation to distribute the irrigation water adequately.

In the clay-loam soils of the type constituting the Victoria area the lateral movement of moisture is very slight. In such soils the furrow system of irrigation is inadequate unless a large number of furrows are used, including furrows under the trees.

Moisture determinations in groves in which alfalfa was being grown as a permanent cover crop show that the irrigation water never penetrated deep enough into the soil to insure an adequate moisture supply for the orange trees.

For a basin having an area of 150 square feet the experiments indicate that approximately 150 pounds of alfalfa or 15 to 20 cubic feet of stable manure will be required each year to maintain an effective mulch.

It is not possible with the water ordinarily available to grow mulching material between the basins sufficient to maintain a satisfactory mulch on the basins. Cover crops, however, can be grown between the basins on winter rainfall to supply part of the mulch, and where water is available in the summer it can be used for the same purpose.

Orange trees on clay-loam soil, such as the Victoria soil, responded more quickly to the mulched-basin system than trees similarly treated on light soils, because the heavier soils under the furrow method of irrigation do not absorb moisture as rapidly as lighter soils. Mulched-basined trees on clay-loam soils showed a marked response to the

treatment in 3 months, while basined trees on light soils required from 6 to 12 months to show a growth superior to that obtained with furrow irrigation and clean cultivation. The mulched basin is not satisfactory on heavy gumbo soils.

The set of fruit was very light throughout the Riverside district in 1915, owing apparently to cold weather following the bloom. In the Sunny Mountain tract, where the mulched basins were first installed in 1913, the average number of oranges per tree on the check trees in 1915 was 116, while on the mulched-basin trees the average number of oranges per tree was 281, or two and one-half times as many as on the check trees. The quality of the fruit on the basined trees was also superior to that on the unbasined trees. In the Victoria tract in 1916 the alfalfa-mulched trees averaged 483 oranges, the manure-mulched trees 242 oranges, and the check trees 182 oranges. In the Eureka tract, where the mulched basins had been installed the preceding autumn, the alfalfa-mulched trees carried on the average 550 oranges, an increase of 33 oranges per tree over the average yield of these trees for the preceding six years. Experiments in this tract with other mulching materials showed a decrease in yield during the first season, due in part at least to the fact that the new root system below the basins was not established at the time the fruit buds were set.

The new leaf growth on the basined trees was less mottled than the new growth on the unbasined trees after sufficient time had elapsed for the mulched-basin system to produce response in the tree growth.

The new leaves on the basined trees were larger and darker in color and had a better texture than those on the unbasined trees, especially on heavy soil.

The new growth of rootlets under the mulch in the basins was very much greater than in the check treatments, the soil in the basins being filled with rootlets to within about 2 inches of the surface.

Great numbers of earthworms were often found in the basins under the mulch, and their burrows honeycombed the entire soil mass. The worms help to incorporate the organic material with the soil, while their burrows facilitate the absorption of water in heavy soils.

No soil crust of any kind has been found in the basins where the mulch completely covered the soil surface. A complete mulch must be maintained at all times, however, to prevent the surface from crusting.

The experiments indicate that alfalfa and bean straw are superior to stable manure for mulching purposes.

In the mulched basins the quantity of humus, as measured by the intensity of the color of the alkaline extract, increased markedly in

the first foot of soil during the summer, but no increase was observable at the greater depths. From 70 to 120 days were required for the mulch in the basins to decompose sufficiently to produce a measurable increase in the humus content. Alfalfa and manure mulches were equally effective in producing this increase in humus. Barley cover crops produced a marked increase in the humus content of the soil 50 days after being disked into the soil.

The use of an organic mulch moderates the rise in soil temperature during the day. The advantages of the mulch, however, are not wholly attributable to this fact nor to the conservation of moisture. Wood shavings when used as mulching material afforded as much protection in this respect as alfalfa or bean straw, yet trees mulched with pine shavings gave yields less than half those obtained with mulches of alfalfa or bean straw.

Surface mulching with organic material, especially when available in quantities sufficient to cover the entire surface, may in the long run prove fully as effective as the use of the mulching material in basins. A more immediate response from the mulched basin may be expected, however, owing to the fact that each time the basins are flooded the soluble portions of the decaying mulch are carried with the irrigation water directly into the soil. In this respect the mulched basin resembles a surface organic mulch in humid regions where the rainfall first passes through the mulch before entering the soil. Many of the citrus soils of California contain so little active organic matter that it is essential to secure the advantages of the applied organic material at the earliest possible date, and this appears to be brought about more quickly by the use of the mulched basin than by organic mulches with furrow irrigation. The mulched basin also appears to be the most effective means of using a limited quantity of mulching material.

The marked response of citrus trees in the experimental tracts under the mulched-basin system justifies its serious consideration by citrus growers. It is still in the experimental stage, and its suitability to local conditions in any instance should be thoroughly tested in an experimental way before installing basins on a large scale. Its final value in the industry can be determined only after it has been so tested in comparison with other systems in commercial practice.

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